

SCIENCE MISSIONS ENABLED BY THE ARES V

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ABSTRACT

NASA's planned heavy-lift Ares V rocket is a centerpiece of U.S. Space Exploration Policy. With approximately 30% more capacity to Trans-Lunar Injection (TLI) than the Saturn V, Ares V could also enable additional science and exploration missions currently unachievable or extremely unworkable under current launch vehicle architectures. During the spring and summer of 2008, NASA held two workshops dedicated to the discussion of these new mission concepts for the Ares V rocket. The first workshop dealt with astronomy and astrophysics, and the second dealt primarily with planetary science and exploration, but did touch on Earth science and heliophysics. We present here the summary results and outcomes of these meetings, including a discussion of specific mission concepts and ideas, as well as suggestions on design for the Ares V fairing and flight configurations that improve science return.

INTRODUCTION

The overarching goal of both workshops was to bring together early in the Ares V design cycle leading astronomers and planetary scientists with the engineers who are designing the Ares V rocket. By doing so, we hoped to find ways to improve the capability of the Ares V to do science without compromising its primary mission of transporting the Altair Lander and supplies to the lunar surface. Of particular importance are issues related to payload environment, such as mass, volume, fairing shape, cleanliness, acoustics, etc. and accommodation issues, such as nuclear powdered payloads, multi-spacecraft

payload capabilities, late payload access, etc. We also wanted to identify other technologies that needed to be pursued and matured between now and 2020 when the Ares V is likely to become available for scientific missions. The goals of these two workshops directly addresses recommendation 7-1 in the Aldridge report, which recommends that "NASA seek routine input from the scientific community on exploration architectures to ensure that maximum use is made of existing and emerging capabilities."

ARES V CHANGES EVERYTHING

It was clear from the outset that the availability of an Ares V changes the paradigm of what can be done in astronomy and solar system science. Unique aspects of the Ares V include its dramatically larger payload capability over existing vehicles. For example, preliminary performance assessments indicate that an Ares V could deliver approximately five times the payload to Mars compared with the most capable existing vehicles such as the Delta IV Heavy. The Ares V is also capable of much larger C_3s (hyperbolic excess speed over escape, squared). This potentially opens up direct missions to the outer planets that are currently only achievable using indirect flights with gravity assist trajectories. An Ares V with an upper stage could perform these missions using direct flights with shorter interplanetary transfer times, which enables extensive in situ investigations and potentially sample return. Another unique aspect of the Ares V rocket is the large 8.8-m interior diameter of its fairing. This enables the launch of very large monolithic mirrors, arrays of precision flying mirrors, or extremely large deployable telescopes. In this paper we discuss some of the specific missions that were considered at the two workshops, as well as discuss some of the technology challenges that remain in making the Ares V enabling for breakthrough astronomy and planetary missions.

ASTRONOMY AND ASTROPHYSICS

The Ares V would allow much larger mirrors to be deployed at Sun-Earth L2 or other locations. Large apertures

translate to greater sensitivity and spatial resolution. This is particularly important for studying faint sources, such as objects in the early universe or exosolar planets.

Telescope Concepts and Missions

In the astronomy workshop seven telescope concepts or missions were presented. Briefly these were:

1. The Single Aperture Far Infrared Telescope (SAFIR) concept. SAFIR is designed to obtain spectra in the far infrared (FIR) ($\sim 20\text{-}300\ \mu\text{m}$) using a 8-m monolithic mirror.
2. The Advanced Technology Large-Aperture Space Telescope (ATLAST). Either 8-m and 16-m aperture mirrors designed to operate at Ultraviolet (UV) and optical wavelengths.
3. Stellar Imager (SI), a large baseline UV/Optical interferometer designed with 200 times the resolution of the Hubble Space Telescope.
4. Generation-X, a large-diameter X-ray telescope with unprecedented angular resolution.
5. Submillimeter Probe of the Evolution of Cosmic Structure (SPECS), which is an interferometer consisting of 4-meter collector telescopes and a Michelson beam combiner with a one-kilometer baseline constrained by tethers.
6. Dark Ages Lunar Interferometer (DALI), which would consist of antenna stations on the far side of the moon. The interferometer is being designed to study the early universe at radio wavelengths.

7. Starshades in the Ares V. This consisted of an overview of what an Ares V could enable in exosolar planet research by deploying large mirrors in conjunction with star shades.

All of these missions have a baseline concepts that can be launched on a Delta IV Heavy. The larger launch mass and volume of an Ares V, however, greatly enhances all of the missions, by allowing the deployment of larger (or more) elements.

Fairing Considerations for Astronomy

Of the seven astronomy concepts presented, only DALI was limited by launch mass. The other six concepts were volume limited. The baseline concept for the shroud shape is biconic, but an ogive shape is a leading contender, since it increases the internal volume. Several of the astronomy concepts (ATLAST, SI, Starshades) favored a taller fairing compared with the baseline fairing that is needed to accommodate the Altair Lunar Lander. The maximum length of the fairing is limited by the height of the Vehicle Assembly (VAB) building at Kennedy Space Center (KSC). The recent redesign of the Ares V to six Delta IV-derived RS-68 engines, and the expansion of the solid rockets to 5.5 segments, has added about 20 feet to the length of the rocket. This reduces the maximum length of the shroud correspondingly. Nevertheless, The shroud volume is extremely large compared with existing launch vehicles. It is fair to say, however, that large astronomy missions are more limited by shroud volume than mass, and that many

astronomy missions would favor a taller fairing.

On-orbit Servicing of Telescopes

The importance on on-orbit servicing of telescopes surfaced as a key issue in the astronomy workshop. This is not surprising considering that the Hubble Space Telescope (HST) servicing missions have dramatically increased the scientific productivity of HST, and that observatories launched by an Ares V are likely to be both large and expensive. The recent very successful Defense Advanced Research Projects Agency (DARPA) Orbital Express mission has demonstrated that on-orbit servicing of astronomical observatories is feasible if the telescopes are designed with standard servicing functions. In addition, the Constellation Program potentially enables human servicing of telescopes throughout trans-lunar space including Sun-Earth (SE) L2. A servicing mission scenario was presented for servicing a telescope in a halo orbit around the SEL2 libration point using the Interplanetary Transfer Vehicle (ITV). The mission requires 35 days and little additional delta-V than is required for Trans-lunar Injection (TLI). In key respects, a more attractive scenario would have the telescopes travel from SEL2 to an Earth-Moon L1 “job site” and service them there with robots and/or astronauts. This jobsite is 84% of the way to the Moon and easily accessible to lunar-capable Constellation architecture.

Astronomy enabled by Ares V

One of the breakout groups was tasked with determining what breakthrough science might be enabled by an Ares V.

While the group concluded that there was no astronomy that was uniquely enabled by an Ares V, observations that might be feasible through other means (for example, with multiple launches on smaller vehicles, and in-space assembly) become more practical with an Ares V. The larger aperture telescopes that can be launched with an Ares V are particularly useful for studies of the early universe, the formation and evolution of large-scale structure in the universe, and exosolar planetary science.

Payload Considerations for Astronomy

The general consensus was that the launch environment of an Ares V should be no more stressful than encountered on the Shuttle. Telescopes are sensitive instruments, but the large payload capability of Ares V, and the fact that most missions are volume, not mass constrained, allows some flexibility to make the telescope more rugged, or to add more support and isolation structures to protect the telescope from launch accelerations, vibration, and acoustic loads. Dynamic and acoustic loads need to be held to those encountered on current heavy launch vehicles. Because of the extremely sensitive instruments, cleanliness is also an important issue. The ability to have a continuous N₂ purge during integration and pre-launch is important. Many of these considerations apply also to the Ares V primary mission of launching Altair, so it is likely that astronomy missions will not impose substantially more stringent conditions inside the shroud.

Is There Value in Simplicity?

A major concern in considering the use of super-heavy-lift launch vehicles is the affordability of the payloads. If cost scales with mass, one can easily imagine payloads that would be unaffordable with today's science budgets. A major discussion topic at the astronomy workshop was, therefore, the trade space between mass and complexity. Complexity allows mission designers to gain performance from a volume and mass constrained launch system. By reducing these constraints, the Ares V enables a new paradigm, namely reducing cost and risk by designing simple, less complex systems. This, in turn, requires rethinking the ground processing and testing infrastructure for simple and rugged, but also larger and heavier spacecraft, apertures and components. Clearly, the astronomy community needs to rethink the way that it designs telescopes for an Ares V launch to keep the payloads affordable. To apply more rigor about our assumptions and conjectures about the cost savings of larger, but less complex telescopes, it was recommended that we compare the current segmented James Webb Space Telescope (JWST) with a monolithic design. Specifically, we should compare the option of a segmented mirror like JWST designed for Evolved Expendable Launch Vehicle (EELV) launch with a monolithic mirror and other mass-unconstrained approaches for Ares V launch.

PLANETARY SCIENCE

A workshop focused on planetary science that could be enabled by an Ares V was conducted the weekend of August

16 and 17, 2008 at NASA Ames Research Center. The goal as in the previous workshop on astronomy was to bring the engineers who are designing the Ares V from Marshall Space Flight Center together with leading planetary scientists to discuss what requirements large planetary science missions might place on the design of the Ares V. The workshop also touched upon Earth science and heliophysics. The much larger payload capacity and escape velocities of the Ares V opens up entirely new approaches to planetary science, especially at the outer planets. A considerable number of innovative mission concepts were presented at the workshop. These are summarized briefly below.

Planetary Mission Concepts

In this section we summarize some of the mission concepts that were presented at the workshop.

1. Chris McKay presented a paper entitled "Sample Return from Europa and Enceladus using an Ares V." He made a key point of noting that the large payload capacity of Ares V permits adding cheap, but useful mass. Examples include extra fuel for propulsive maneuvers, shielding (lead) to protect from harsh radiation, drill strings and casings for drilling, and redundancy. This cheap mass potentially enables sample return from Europa, since it would have the payload capability of shielding a lander on the surface and providing sufficient fuel for propulsive maneuvers out of the gravitational well of Jupiter. At Enceladus, the Ares V could carry the fuel needed to slow down for sample capture from the plumes on Enceladus, or create an

artificial plume on either Europa or Enceladus by firing a copper projectile at the surface.

2. Tom Spilker et al. presented a paper entitled "A Multi-Spacecraft Mission to Saturn Enabled by Ares V: Atmospheric Probes, Ring Observer and 'Beyond Cassini' Orbiters." The mission scenario consists of two high-speed direct probe entries, microwave radiometry (MWR) for deep atmosphere sounding, aerocapture of the Saturn Ring Observer (SRO) and a "Beyond Cassini" orbiter. Simultaneous deep probes and MWR could meet the science objective of measuring heavy elements and water abundances in the Saturn atmosphere to 100 bars. The SRO is designed to aerocapture into a Saturn ring observation orbit. The SRO would provide a huge advancement in our understanding of outer planet formation and validation of the planetesimal accretion model. This mission requires advancing a number of key technologies such as thermal protection systems and in-atmosphere communications from deep probes.

3. Dale Cruikshank presented a paper entitled "Science with Large Planetary Probes Enabled by Ares V: Exploration of the Kuiper Belt." His contention was that an Ares V afforded much larger instrument payloads to explore Kuiper Belt objects. Key measurements that are required include high-resolution surface imagery, atomic, molecular, and isotopic composition of surface materials, and the composition of atmospheric gases and sputtered surface materials. The Ares V can provide the instrumentation to make these key measurements by providing the capacity for larger apertures, more capable detectors both in wavelength

range and sensitivity, mass spectrometers with larger mass range and higher sensitivity, power on the order of a few kW, high data volume and rate, surface probes and autonomy, and other operational innovations.

4. Amy Barr presented a paper entitled “Alternative Approaches to Outer Solar System Exploration.” She discussed a number of missions that could benefit from an Ares V. For example, trying to assess the habitability of Europa by sampling below the radiation processed top layer or sampling the plume of Enceladus. She suggested in-situ analysis as a means of obtaining low-risk prompt science return. She argued for a Callisto orbiter. Studying this satellite of Jupiter, which is thought to be a homogenous ice/rock mixture, could constrain the lifetime of the solar nebula. Finally, she recommended a Neptune/Triton system orbiter, which might be enabled by propulsive orbital insertion using the extra fuel that only an Ares V would be capable of carrying.

Constellation Enabled Exploration

Several missions presented described planetary exploration that requires not only the Ares V, but other elements of the Constellation architecture as well.

1. Mark Bullock presented a paper entitled “The Human Exploration of Venus.” In this concept, humans explore the surface of Venus through telepresence robots while the humans reside inside the Crew Exploration Vehicle (CEV) in orbit around Venus. The human mission is two years, while the surface robotic mission is designed to last 17 years. Vehicles are required at multiple locations on the surface of

Venus to understand the planet’s geological history. These vehicles would incorporate some combination of high temperature electronic and mechanical systems and Stirling-cycle power and cooling. These large massive vehicles could only be placed on the surface with the payload capacity of an Ares V. For this mission to become a reality we need to advance technologies such as high bandwidth and high-temperature electronics, sensors, digital processing and memory, motors, actuators, and encoders. However, the technology to put several large capable telepresence robots on the surface of Venus for an extended period is achievable with the payload capacity of an Ares V. An additional interplanetary CEV with Ares V cargo could put a crew around Venus that would enable real-time surface exploration.

2. Paul Abell presented a paper entitled “Constellation Enabled Missions to NEOs.” They analyzed several mission concepts, but the preferred approach is to launch the crew on an Ares I and the Earth Departure Stage (EDS) and the Lunar Surface Access Module (LSAM) on an Ares V. This scenario enables a crew of three with telerobotic exploration and EVA with a 7-14 day visit at the Near Earth Object (NEO). Total mission time is 90-180 days to existing NEO targets that could be reached in the 2020-2035 timeframe. More targets will likely be identified in on-going surveys of NEOs. The Constellation elements would be able to achieve the necessary delta-V that is required for rendezvous and return to Earth. There is both science and exploration drivers for such a mission. For example, this would help assess the potential for in-situ resource utilization.

This would also provide operational experience and potentially help identify more efficient and cost effective deep space exploration architectures.

3. Richard Mattingly presented a synopsis of the “Constellation-enabled Mars Mission Exhibiting New Technology (CEMENT) study.” The study objective was to examine the flight elements of the Constellation Program for application to human precursor robotic missions to Mars. The study requirements included aero-capturing and landing a large mass on Mars using an aeroshell, and returning multiple samples to Earth using a single Ares V. This mission study included performing pinpoint landing on Mars, robust Ka band Earth-Mars telecom, subsurface exploration to 10-m depth and In-Situ Resource Utilization (ISRU). However, technologies such as aerocapture need to be matured before the mission can be flown.

Earth Science and Heliophysics

The Earth science community has recently developed a decadal plan to guide priorities for future missions. Earth is a complex system requiring a full complement of observations of key climate, weather, and solid Earth parameters to monitor global change. The current approach is to launch relatively small spacecraft to meet these measurement needs. However, looking toward the future (2020 and beyond), one can at least envision missions that might be enabled or significantly enhanced by an Ares V. For example, in geostationary orbit (GEO) large aperture (>10 m) microwave sounders could provide useful spatial resolutions of temperature and rain measurements for

severe weather monitoring/prediction, and large synthetic aperture radars could be used for surface wind predictions. Furthermore, one could envision Earth science observatories at the L1 and L2 Lagrange points. Advantages include a synoptic view, sunrise to sunset coverage, excellent time resolution, and long integration times for extraction of small changes with time.

There are heliophysics missions that are significantly enhanced by an Ares V as well. The large C₃ capability and payload capacity (needed to carry an upper stage) make the Ares V enhancing for studies of the interaction of the outer heliosphere and local interstellar medium. Charles McNutt presented a paper entitled the “Interstellar Precursor Probe.” The goal is to reach distances from the Earth of 200 Astronomical Units (AU) in a reasonable time span (e.g. ~20 years). To achieve this requires a combination of very high launch C₃, gravity assist at Jupiter, and ion engines powered by a high-specific-energy radioisotope power source (REP). Current launch vehicles would not be able to reach these distances in this short of time.

Sample Return Using Ares V

A breakout group chaired by Chris McKay focused on sample return missions that could be carried out with an Ares V, but are somewhat beyond the capability of current launch systems. The advantages of additional payload capacity to interesting planetary targets gives flexibility to solve problems such as the need for a robust landing system, shielding from radiation, micro-meteorites, etc., site selection, and planetary protection issues. It allows for

shorter flight times and longer data acquisition times, and the simultaneous use of both orbiters and landers. It can provide for redundancy, and for better sample acquisition systems such as deep drills and sample selection tools like X-Ray Fluorescence (XRF). This results in a mission with more science return per cost and lower risk.

Specifically at Europa an Ares V would enable surface landers and the mass to provide adequate shielding. It could enable impact sampling by providing propellant to reduce velocity to collect a sample non-destructively and then sufficient propellant to accelerate for rapid return to Earth. Sample preservation (refrigeration) on return may also require mass. On Enceladus, one could carry out non-destructive sampling directly from the plumes. Titan poses real challenges for sampling. Ideally one would want to get both atmospheric and surface organics due to the processing that occurs on the surface. Also the diversity warrants multiple site selection, such as a site with surface liquid or a cryovolcanism site. Sample return requires cold O₂ free conditions. The Ares V makes sample return from these three interesting moons feasible. Enabling sample return does raise infrastructure issues such as the need for adequate containment and curation facilities.

Payload Considerations for Planetary

One of the key purposes of the two workshops was to provide feedback to the Ares V designers on payload development and accommodation issues. Planetary payloads have many of the same requirements as discussed previously for astronomy payloads. In

addition, the shroud design must not prevent the use of radioactive power sources. Late payload access is needed both for nuclear powered payloads and for fueling of a Centaur or other upper stage. Hazardous propellant handling is needed for fuels such as nitrogen tetroxide and hydrazine. Stringent cleanliness requirements may be necessary for payloads that need to be sterilized for planetary protection needs. Propellant issues may not be a major additional requirement for the Ares V, because they have to be addressed for the baseline mission of transporting the Altair Lunar Lander.

Technology Maturation Needs

Throughout this paper we have noted the need to mature certain technologies if we are to realize the full potential of the Ares V. In this section we summarize some of the key technologies that require further development.

For astronomical observatories further technology developments need to be made into advanced optics technologies such as replication, improved wavefront sensing and control, as well as advanced deployment and assembly technologies.

For planetary missions further technology development is needed for drill systems to penetrate below the surface of Mars and Europa. High-temperature electronics and sensors are needed for studies of Venus and Mercury. Further development of efficient coolers are needed both for cooling on Venus and for sample return from the outer planets. Although an Ares V can preclude the need for aerocapture by enabling propulsive orbital insertion, it could also be useful in maturing this

technology, since it would be capable of launching a large aeroshell.

Infrastructure Considerations

The dramatically increased shroud volume on the Ares V forces us to reconsider our flight development test facilities. For example, the sample return and outer planet missions that are enabled by an Ares V require infrastructure support, such as preparing for sample return by building containment and curation facilities. Reentry from outer planets are at very high velocities, where the heating on the re-entry vehicle is predominately radiative. Upgrades to facilities such as arc-jets will be required to test larger aeroshells and to develop higher temperature ablative materials.

The increased capability that an Ares V provides for planetary research will require upgrading the capacity of the Deep Space Network. Ares V has the payload capacity to carry more robust antennas capable of higher bandwidth communication.

Payload integration becomes a larger issue as well. How do you get an 8-m monolithic telescope to the payload integration facility at KSC? Thoughts need to be given to the requirements and capabilities needed to service and process Ares V class payloads early on to reduce life cycle cost and schedule risk. Leaving logistics to the end of the design cycle can result in unexpected cost.

GETTING THE WORD OUT

The Ares V represents a tremendous opportunity to do breakthrough solar

system science and astronomy. However, the science communities have not given much thought to this emerging opportunity. Planning has already begun for the astronomy and astrophysics decadal survey (2010-2020). Preparations are about to begin for the next planetary decadal survey. If the potential of Ares V are to be considered by these panels, we must engage these science communities in the near future. The workshops are a first step. The astronomy workshop report has been published as a NASA Conference Proceedings (NASA/CP-2008-214588). A similar workshop report will be published for the second workshop on solar system science. Further impetus for bringing the message to the science community should come from the National Research Council (NRC) report that is due out in November of 2008. The opportunity to present here at the International Astronautical Congress (IAC) meeting is especially important, as it allows us to address the international community. International partnerships will be particularly important for the large flagship missions that the Ares V will enable.

SUMMARY

The Ares V changes the paradigm of what can be launched, because its launch performance (C_3 versus payload) is far above that of any other current vehicle. In addition, its launch fairing is dramatically larger. This allows launching large, complex systems, greater science instrument mass and mass fraction, larger electrical power supplies, greater post-launch delta-V, more mass for shielding, and greater mass for lower-complexity engineering solutions. This translates into an earlier

return on science, a reduction in mission times, and greater flexibility for extended science missions. It is particularly enabling for sample return, which takes advantage of all of the Ares V capabilities. We encourage the science community to think big, because an Ares V changes everything.